National Aeronautics and Space Administration

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SPACE LAUNCH SYSTEM

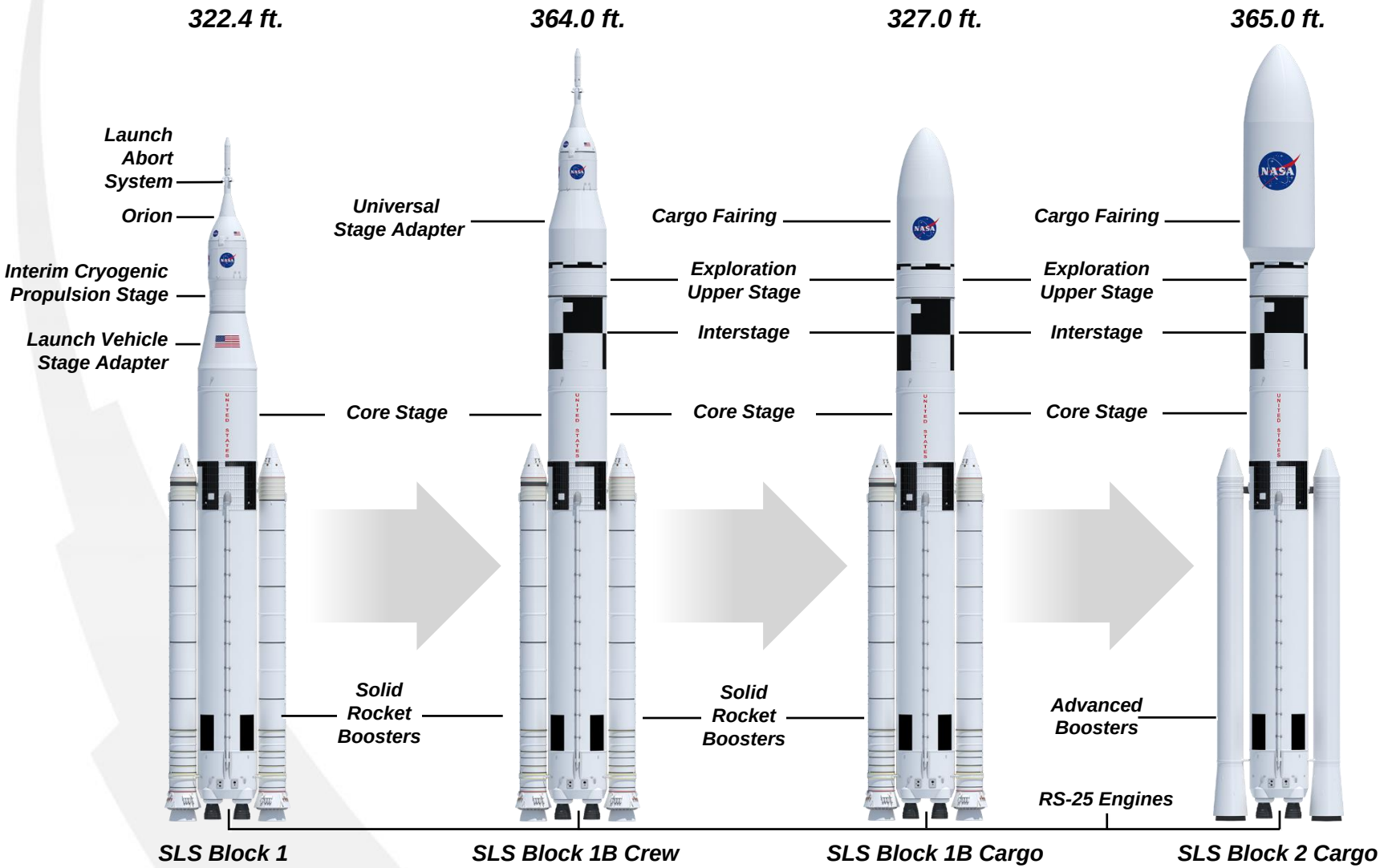
SLS at Critical Design Review

Chris Crumbly

Manager,

Spacecraft/Payload Integration & Evolution

SLS Evolution Overview

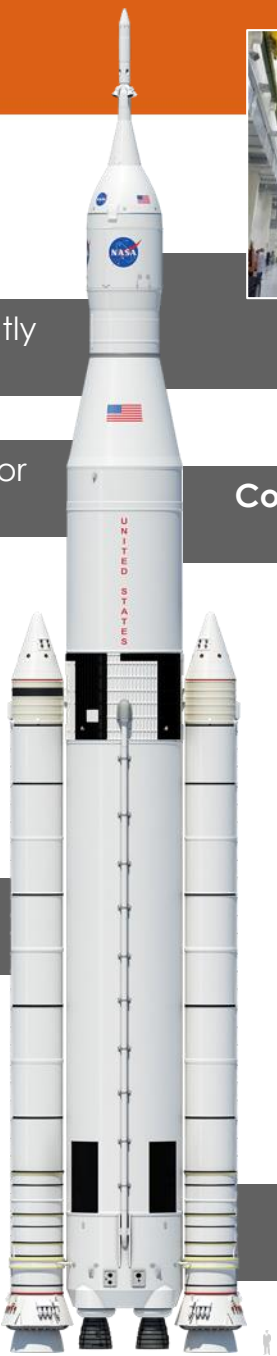


Building Today

Interim Cryogenic Propulsion Stage: Test article currently in production; flight article began July 2015.

Stage Adapters: First flight hardware launched on Exploration Flight Test-1 in Dec. 2014.

Avionics: Software Integration Test Facility preparing for qualification in second quarter 2016.



Core Stage: Production is underway on hardware for both test articles and EM-1 vehicle.

Boosters: Qualification Motor-1 test completed in March 2015.

Engines: RS-25 testing has begun at Stennis Space Center; renovations underway to B-2 stand.

SLS MILESTONES SCHEDULE

2011	2012	2013	2014	2015	2016	2017	2018
Mission Concept Review ✓	System Requirements Review/System Definition Review ✓	Preliminary Design Review ✓	Key Decision Point-C ✓	Critical Design Review ▽		Design Certification Review ▽	Launch Availability ▽

Booster Development Test

Engines Delivered to Inventory

RS-25 Development Testing Begins

Booster Qualification Tests

RS-25 Flight Test Firings

Boosters Fabrication Complete

Booster Assembly at KSC

Manufacturing Tooling Installation

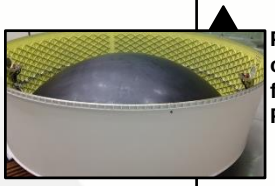
Core Stage Production Begins

Core Stage Assembly Complete

Core Stage Structural Testing

Core Stage Test-Firing

SLS Design Chosen



Production of Adapter for Orion Flight Test

Integrated Spacecraft and Payload Element Production Begins

ISPE Structural Testing

SLS Launch Readiness

Concept Studies	Design & Development	Final Design & Fabrication	System Assembly, Integration and Test, Launch Checkout

Payload Accomodation Concepts Under Study

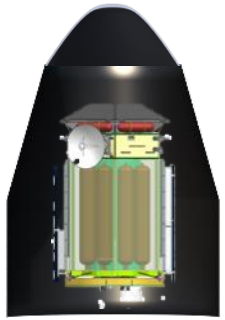
Mission concepts with Universal Stage Adaptor

Mission concepts with 8m and 10m fairings

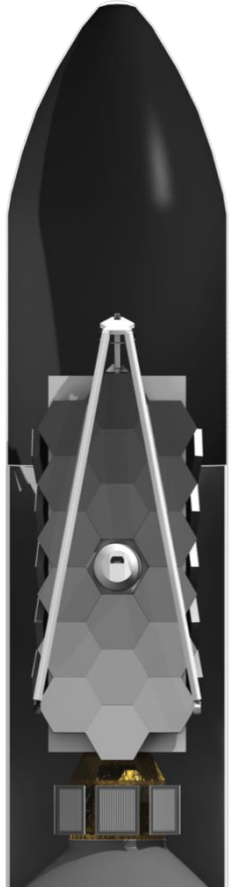
Orion with short-duration hab module

5m fairing w/robotic lunar lander & short-duration hab module

Science Missions



ARM Mission



8m fairing with large aperture telescope

10m fairing w/notional Mars payload

total mission volume = ~	400m3	600m3	400m3	400m3	1200m3	1800m3

Selective Laser Melting Road to Flight

Component Development

- Built and hot-fire tested J-2X gas generator discharge duct

- J-2X fuel turbine exhaust duct maintenance port plug is being built for engine hot-fire testing

- Successfully built RS-25 internally tied bistra

- Will build and water flow test RS-25 POGO Z-baffle.

- Plans in work to green run and certify SLM POGO Z-baffle for use on RS-25

Material and Process Development

- Created draft SLM Engineering and Quality Guidelines document
- Developing inspection techniques
- Procurement of SLM machine for MSFC Materials Lab
- Mechanical testing of material samples, developing materials verification matrix
- Working with Army and Air Force on material development

Build flight rationale → Fly SLM components

Additional MSFC Activities

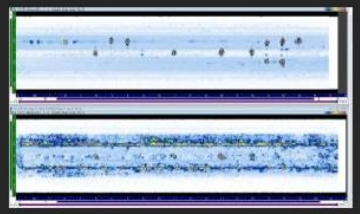
- Participation in 3 separate proposals for Air Force Broad Agency announcement, pilot Additive Mfg Innovation institute
- Engineering Development:
  - Unique tooling fabrication
  - injector elements and various other components for MSFC component test bed
  - Turbopump components
  - Small thruster development

Activity Completed

Activity in work

Advancing the State of the Art

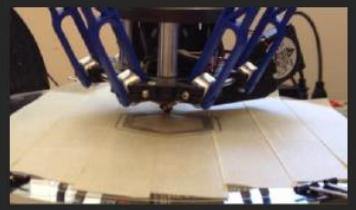
Friction Stir Weld (FSW) Performance Improvement: Sam Russell



Objective: Measure stress concentration effect in FSW welds and develop improved phased array ultrasound testing technique. Fit FSW tool with end mill for shaving post-weld.

Accomplishments:
- Welded two sets of panels using FSW
- Prepared first set for inspection in usual manner and shaved second set by milling
- Used panels to estimate phased array testing detectability of defects in the surface
- Cut samples from panels and pulled in a tensile test machine to measure the strength of the shaved and unshaved panels

Additive Manufacturing (AM) Infrared Inspection: Darrell Gaddy



Objective: Develop real-time inspection technique using infrared camera imaging and processing. Provide inspection of internal geometry that is not currently possible. Reduce time and cost for producing AM parts by eliminating post-production inspections.

Accomplishments:
- Proved the feasibility of infrared hardware detecting AM process
- Developed custom software which created 3D geometry files of the additively manufactured part

Cryoinsulation Development: Alison Protz

Objective: Investigate low-Global Warming Potential (GWP) cryoinsulation foams as a proactive risk mitigation for SLS Core Stage. Perform a market survey and begin bench scale lab testing of low-GWP cryoinsulation foams.

Accomplishments:
- Completed market survey for low-GWP cryoinsulation foams
- Determined that primary vendors are focused on blowing agents requiring further development
- Smaller vendors have alternative low-GWP blowing agent possibilities

Chromium VI Free Primer Development: Michael Alldredge

Objective: Evaluate corrosion protection capability of multiple commercially-available hexavalent chromium-free non-hazardous primers for cryogenic applications

Accomplishments:
- Evaluated 4 primer candidates, which were selected in phase 1 of project
- Determined that Desoprime CF/CA 7502 has potential for further screening based on physical tests and cryogenic performance

Low-Profile Diffuser (LPD): Mike Martin

Objective: Develop a diffuser concept to replace existing types with a high performing, low profile design to enable more propellant capacity and increase SLS performance

Accomplishments:
- Completed flow testing of prototype diffuser to validate CFD models
- Analyzed test results to determine that good agreement exists between CFD and test data

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SLS

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Advancing the State of the Art

Testing of SLM Turbomachinery: Jason Turpin

Objective: Design, fabricate, and spin test to failure, a Ti6-4 hydrogen turbopump impeller that was built using the Selective Laser Melting (SLM) fabrication process. Perform material testing on coupons.

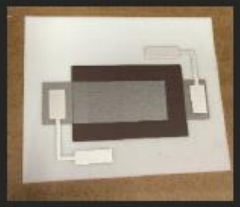
Accomplishments:
- Completed design of the impeller
- Fabricated SLM impeller and material coupons
- Completed structured light scanning and inspection
- Completed spin burst testing, material strength data development, and data analysis

Material Properties Development: Ken Cooper

Objective: Develop and characterize Selective Laser Melting (SLM) parameters for additive manufacturing of Inconel 625 and Ti64. Generate reduced design allowables database of expected SLM properties.

Accomplishments:
- Evaluated 100 samples to determine effects of changes in global energy input on hardness of coupons
- Built a sample set of 50 coupons to test resulting tensile strength at room temperature

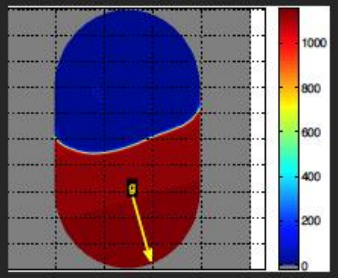
Solid State Ultracapacitor: Terry Rolin



Objective: Develop a solid-state ultra-capacitor to replace batteries. Focus on internal barrier layer capacitor structures composed of coated barium titanate (BT). Fabricate/test single layer ultra-capacitor.

Accomplishments:
- Fabricated ultracaps from coated BT powders using spark plasma sintering; measured permittivity values at MSFC
- Evaluated composite polyimide/BT dielectric materials, and developed new 3D printing processes and materials
- Evaluated many variations of single layer ultracap cell

LB Method for Zero-g Propellant Dynamics: Joey Powers



Objective: Develop a new capability to predict propellant sloshing effects on spacecraft vehicle dynamics in low-g environments

Accomplishments:
- Investigated Lattice Boltzmann method (LBM) for propellant dynamics in micro-g
- Developed modular two-dimensional flow solver
- Demonstrated stable two-phase flow with accurate steady-state density for a cryogen in a closed domain

Performance of Composite Structure: Alan Nettles

Objective: Present information on composite materials properties of relevance to facilitate use for shroud and interstage structures on SLS vehicle. Seek to reduce cost, improve reliability and performance of composite dry structures.

Accomplishments:
- Presented five topics to SLS Advanced Development community to date
- Topics included motivation for use of composites, roles of testing and design